F61: Nuclear Magnetic Resonance

Paris J. Huth & Q'inich Figueroa

May 2024

Abstract

In Protocoll we will examine the usage nuclear magnetic resonance to identify probes and reveal the structure of objects.

1 Basics

1.1 Basics of Nuclear Magnetic Resonance

Nuclear Magnetic Resonance techniques relay of the interaction between the magnetic dipole moment

$$\vec{\mu} = \hbar\gamma\vec{S} \tag{1}$$

of nuclei with non-zero spin S and an external magnetic field $\vec{B_0}$. In the following paper γ represents the gyromagnetic ratio of protons:

$$\gamma_{proton} = 2.6752 \cdot 10^8 \,\mathrm{sec}^{-1}\mathrm{Tesla}^{-1}. \tag{2}$$

The resulting interaction energy is defines as:

$$\Delta E = -\vec{\mu} \cdot \vec{B_0}. \tag{3}$$

In a classical description, this interaction yields two states for the orientation of the protons's magnetic dipole in the external magnetic field: μ_+ (parallel) and μ_- (antiparalle). For a macroscopic sample of N protons, both numbers of occupied states N_+ and N_-, the sum of which comprises N, can be approximated by a Boltzmann distribution:

$$N_\pm = N_0 e^{-\frac{E_0 \pm \Delta E}{kt}} \tag{4}$$

with N_0 as a normalization factor. However $N_+ > N_-$,since the parallel state is energetically favorale. The predominance of protons in the parallel state leads to a macroscopic magntization, whose ground state is

$$\vec{M}_0 = \frac{\mu N}{V} \sinh\left(\frac{\mu B}{kT}\right) \vec{e}_z. \tag{5}$$

In our case, a weak field ($\mu B \gg kT$), the formar expresion simplifies to

$$\vec{M}_0 = \frac{N}{V} \frac{\hbar^2 \gamma^2 I(I+1)}{3kT} \vec{B}_0 \propto \frac{\vec{B}_0}{T}, \tag{6}$$

i.e the law of Curie.

In general, the magnetization can have a macroscopic state characterized by $\vec{M}_0$ minimizes the energy.

1.2 NMR signal

1.3 Relaxation Time

1.4 Chemical shift

2 Measurements

3 Analysis

4 Critical Discussion